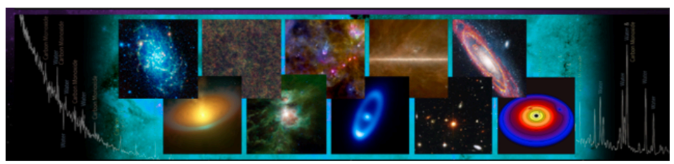
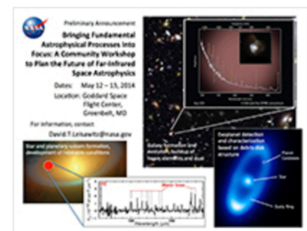
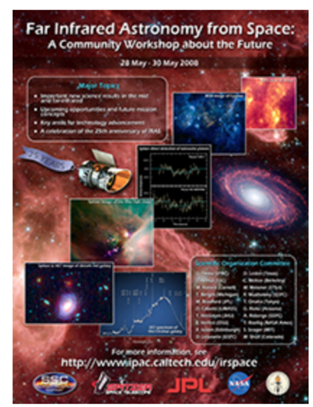
Report on the June 2015 FIR Workshop

L. Armus (Caltech/IPAC)

June 3rd - 5th 2015
Caltech's Beckman Institute
Pasadena, CA







NASA is seeking input from the science community that will culminate in a decision to support studies of three or four large missions to prepare for the next Decadal Survey in Astrophysics. A white paper released by NASA's Astrophysics Division lists four candidate missions, including a Far-Infrared Surveyor mission. This mission is listed because it was recommended in the Astrophysics Roadmap, *Enduring Quests, Daring Visions,* which you can find on the same web site. The community now has an opportunity to comment on the candidate missions and to recommend additions to or deletions from the initial candidate list.

Community input will be provided to NASA's Astrophysics Subcommittee through its three Program Analysis Groups (PAGs). The Far-IR Science Interest Group comprises all interested members of the community and reports to the Cosmic Origins PAG (COPAG). Recently, the COPAG issued an RFI for short 1-2 page whitepapers addressing the candidate missions. The listing of recent meetings as well as the submitted whitepapers can be found on the COPAG community input page. This call for whitepapers, along with other aspects of the large mission study schedule and NASA's charge to the PAGs was discussed during the most recent COPAG town hall meeting on 10 March 2015.

Far IR Surveyor Workshop

http://conference.ipac.caltech.edu/firsurveyor

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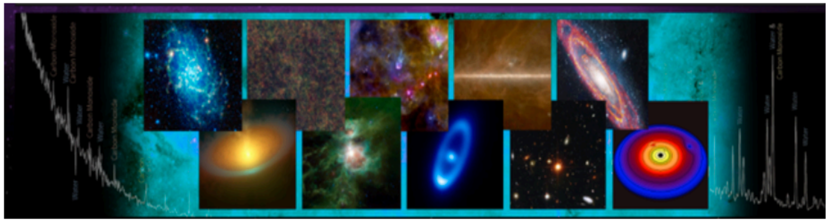

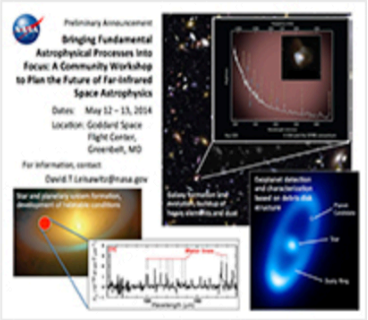

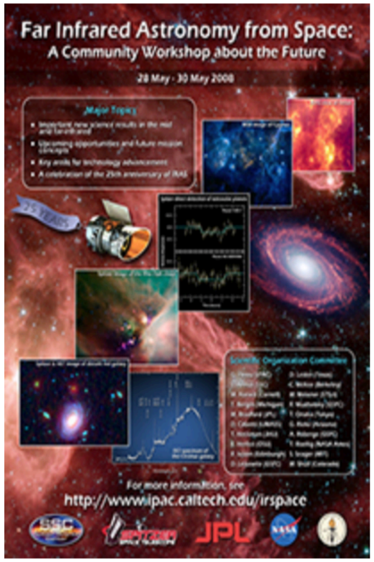

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Preparing for the 2020 Decadal Survey

- Key task: prioritize large missions to follow JWST and WFIRST.
- NASA whitepaper "Planning for the 2020 Decadal Survey" outlined the plan for providing information to the committee on a small set of large mission concepts for detailed study in 2016/2017.
- Four candidate large missions, identified in the 2013 NASA Astrophysics Roadmap were listed in the whitepaper:
  - FIR Surveyor
  - Habitable-Exoplanet Imager
  - UV/Optical/IR Surveyor
  - X-ray Surveyor
- Detailed studies would be provided by Science and Technology Definition Teams (STDTs):
  - define science objectives, strawman payload, identify technology needs, DRM proof, and conduct a cost estimate.

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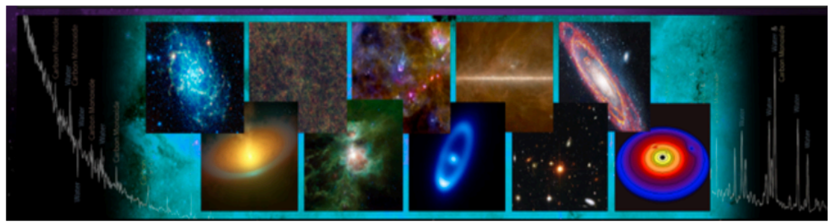
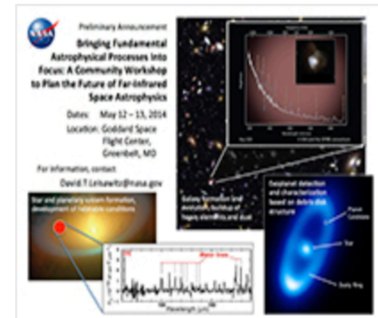
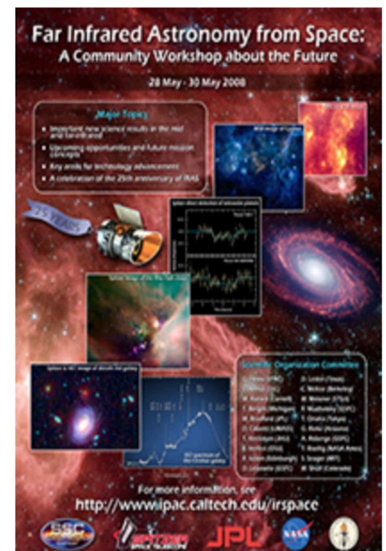




- This was one of a series of FIR workshops held in the US and Europe since 1998. The FIR community is alive and active.

- The most recent workshops have websites:
  - 2014 (http://asd.gsfc.nasa.gov/conferences/FIR)
  - 2015 (FIR Surveyor)
  - 2015 (http://www.ucl.ac.uk/fisica-london-workshop)



Goals of the June 2015 workshop

- Develop and articulate the best science case for a FIR Surveyor. Highlight the key, unique science questions which can be addressed with a large, FIR mission.

- Reach consensus and provide a strong endorsement and baseline concept for a FIR Surveyor that would fit within the broad outline endorsed by the NASA Roadmap committee.

Architectures considered at workshop for the FIR Surveyor:

- Large filled aperture, cold FIR telescope
- FIR Interferometer

>> Report/workshop summary delivered to the PAGs in July 2015.

>> the report, along with all the talks, are available on the workshop website.

Far IR Surveyor Workshop

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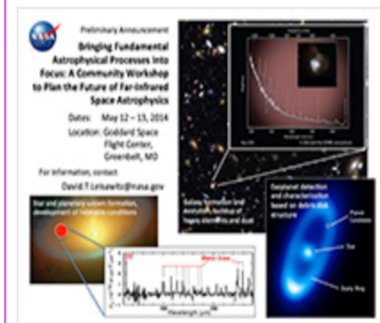
From Early Galaxies to Habitable Planets: The Science Case and Concept for a Far-Infrared Surveyor

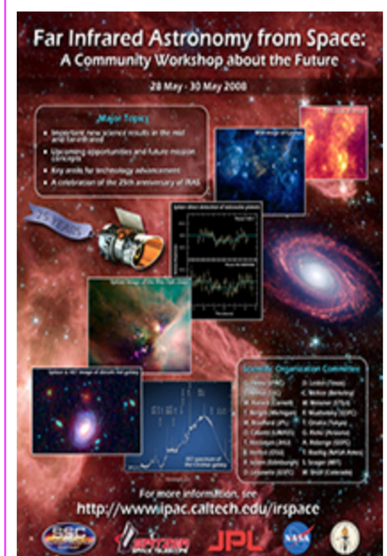
L. Armus, J. Bauer, D. Benford, E. Bergin, A. Bolatto, C.M. Bradford, C. Chen, A. Cooray, N. Evans, D. Farrah, J. Glenn, P. Goldsmith, A. Harris, G. Helou, D. Leisawitz, D. Lis, P. Marcum, G. Melnick, S. Milam, L. Mundy, D. Neufeld, K. Pontoppidan, A. Pope, M. Rizzo, K. Sandstrom, K. Sheth, E. Wright. *and the participants in the June 2015 FIR community workshop*

1. Introduction

1.1. Background

The far-infrared spectral region is home to most of the energy emitted by a broad range of astronomical phenomena, from stars and planets in formation to young galaxies building their stellar populations and feeding nuclear black holes. The typical UV/optical photon from a young star over the history of the Universe has been absorbed by dust, so observations at these wavelengths probe only a fraction of the activity in galaxies over Cosmic time. In marked contrast, the far-infrared (FIR, 30-300 μm) provides direct access to the inner workings of galaxies and Galactic star-forming regions, and offers many of the most powerful spectroscopic diagnostics from ions, atoms, and molecules. These diagnostics probe HII regions around young stars, the gas surrounding powerful Active Galactic Nuclei (AGN), and the Interstellar Medium (ISM) in galaxies over a huge





Workshop summary & COPAG report

- 150 members of the community attended from over 40 institutions.
  >> Great interest in the US community for the next generation FIR telescope.

- Discussion focused on how the FIR provides direct access to:
  - powerful spectroscopic probes of all phases of the ISM from atoms to complex, organic molecules
  - the composition and life-cycle of dust in all environments
  - the inner regions of star-forming systems, starburst galaxies, and buried AGN over a significant fraction of cosmic time

- The two over-arching questions that can be uniquely addressed with a FIR Surveyor, as discussed in the report, are:
  - What controls the evolution of galaxies, the formation of stars and the growth of black holes through cosmic time?
  - How did the composition of the Universe evolve from primordial gas to habitable planets?

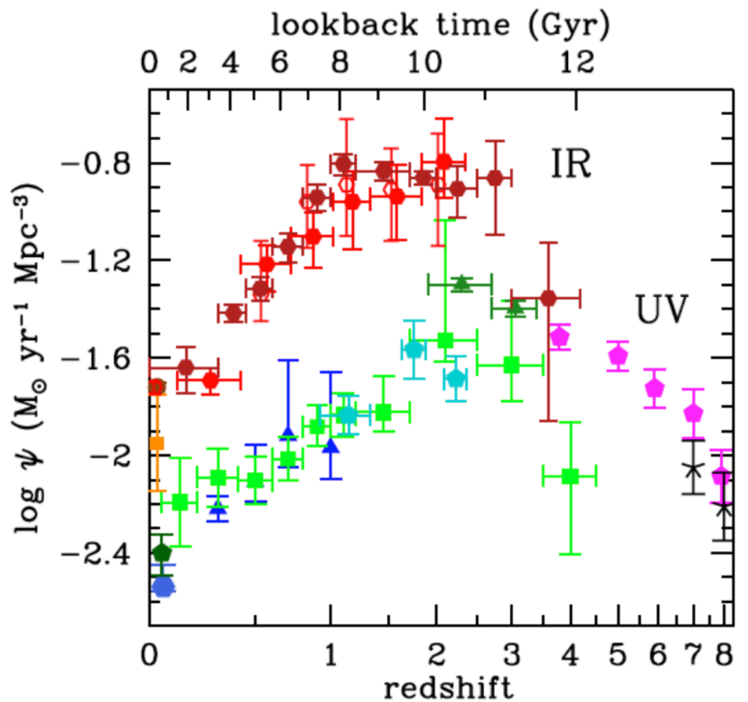


Fig. 2: Star formation densities in the IR and UV as a function of redshift from Madau & Dickinson (2014). The vast majority of the energy produced by young stars to z~3 emerges in the IR.

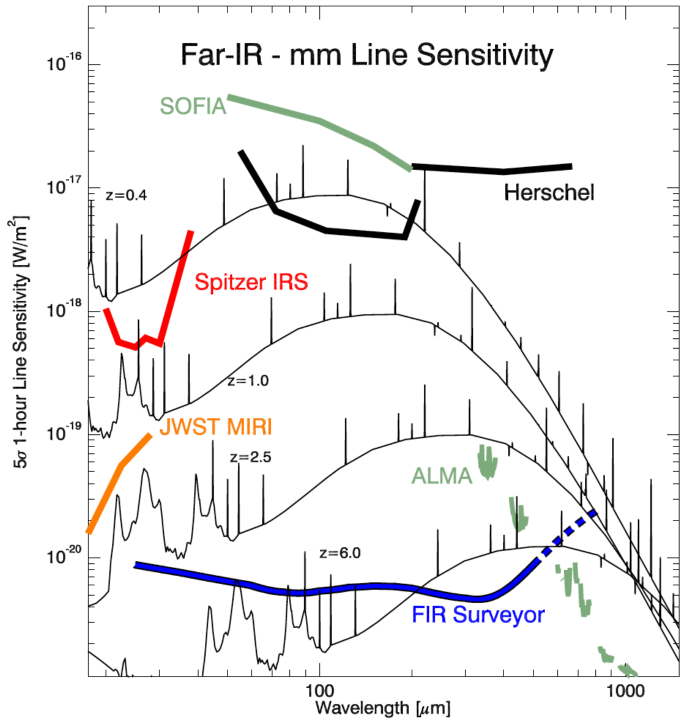


Fig. 1: The SED of a 10^{12} $L_\odot$ star-forming galaxy is shown at a series of increasing redshifts from z=0.4 to z=6. The sensitivities of Spitzer/IRS, JWST/MIRI, SOFIA, Herschel, and ALMA are shown. The sensitivity of the **FIR Surveyor** is shown in dark blue, delivering more than two orders of magnitude gain over existing and planned instruments in the far-infrared. The dotted line is a possible extension of the FIR Surveyor to 800 μm.

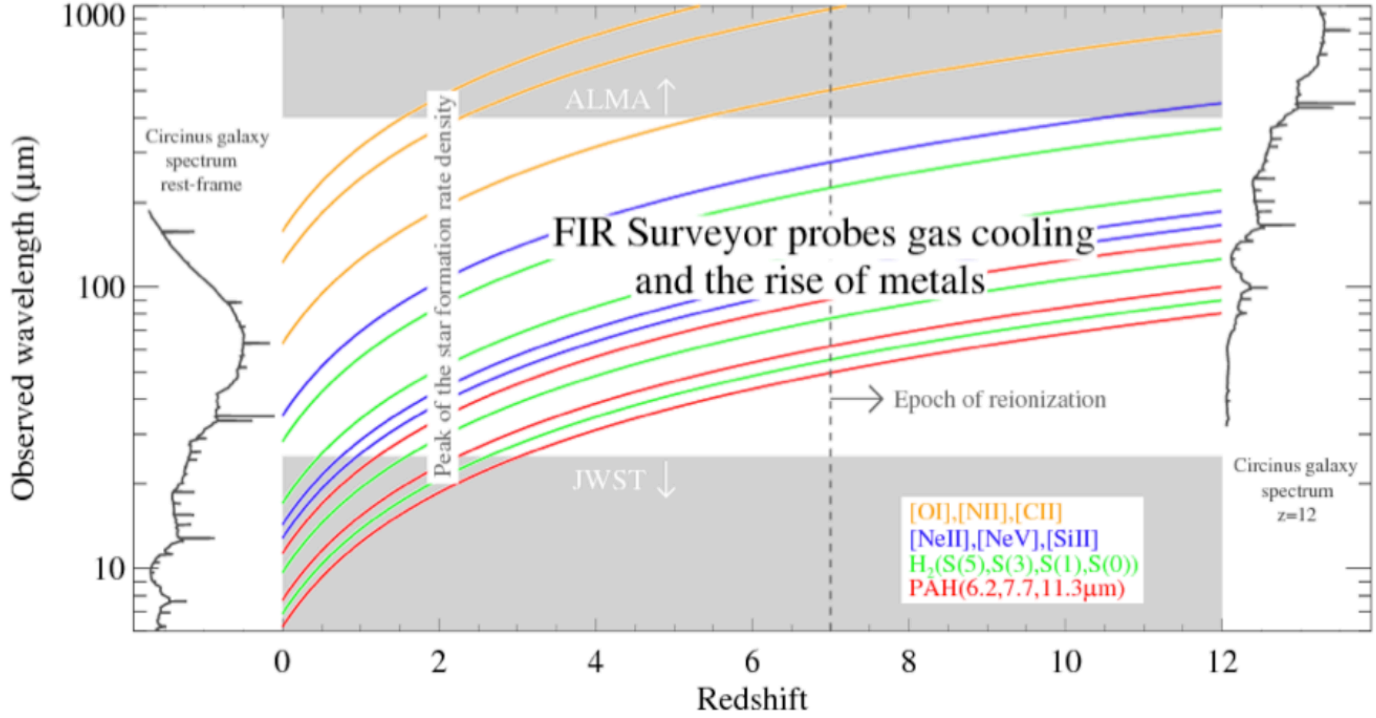


Fig. 3: Important infrared diagnostic lines as a function of redshift. With these lines the FIR Surveyor will be able to quantify AGN and star formation and constrain the conditions of the ISM in galaxies from the peak of the star formation rate density to the epoch of reionization. The rest-frame spectrum of the Circinus galaxy, a dust-enshrouded active galaxy, is shown on the left, and redshifted to z=12 on the right, to highlight the rich spectral region covered by the FIR Surveyor. The FIR surveyor will fill a crucial gap between JWST and ALMA by directly probing the emission from dust, atomic and molecular gas at high redshift.

Key questions

What controls the evolution of galaxies, the formation of stars and the growth of black holes through cosmic time?

- What physical mechanisms drive the cosmic SFRD? How do these drivers vary with morphology, mass and environment?
- How do baryons cycle from primordial gas to stars and back within dark matter halos?
- What role does feedback play in the assembly of the Hubble sequence?
- How do IR-bright galaxies trace large-scale structure?
- What controls the evolution of clouds to stars inside galaxies? What is the role of magnetic fields?

Key questions

How did the composition of the Universe evolve from primordial gas to habitable planets?

- What is the cosmic history of the rise of metals and dust?
- What controls the life-cycle of interstellar dust?
- What is the trail of water from molecular clouds to planets?
- How are volatiles delivered from proto-planetary disks to habitable planets? How do the gas reservoirs evolve in PPDs?
- How was the Solar System arranged into its present form?

Workshop summary & COPAG report

- An interferometer has advantages in terms of spatial resolution (dissecting galaxy nuciei and SF regions, disks, etc.)
- A strong preference for the large, filled aperture FIR telescope architecture as the best way to address the key science questions in the late 2020's, early 2030's.
    - telescope temp. < 4K, actively cooled
    - telescope diam. ≈5-6m, potentially off-axis
    - telescope FoV ≈1 sq. deg. at 500 microns
    - wavelength coverage of 25-400 microns (or longer)
    - total detectors ≈1E5
    - instruments: wide field, broad-band imaging spectrometers (R~500), high-res. spectrometer (R~3E5), continuum cameras potentially with pol. capability.

Lines: 3-5E-21 W m^{-2} (5σ, 1hr)
Continuum: 1 sq. deg. in 1hr to 40μJy (3E10 $L_{\odot}$ at z≈5 @70μ)

Science Theme	Questions	FIR Surveyor Observations	FIR Surveyor Capabilities
The history of star-formation and black hole growth in galaxies	What physical mechanisms drive SF and BH growth in the early Universe? How do baryons flow in and out of galaxies?	Pointed observations of galaxies from z=1-10: PAH bands, FIR fine-structure lines, H2 and molecular absorption features, dust continuum SED	R~500, Full 25-400 μm coverage; 10^{-20} W m^{-2} line sensitivity
	How do IR bright galaxies trace the large-scale structure of the Universe?	Large area, blind continuum and spectral surveys. Spectroscopy over 10s sq. deg., continuum over 1000s of sq. deg.	Sensitivity and mapping speed. Wide-band multi-beam R~500 spectroscopy with large format arrays
	How do galaxies evolve over the last half of Cosmic time to populate the Hubble sequence?	Continuum and spectral line maps of thousands of $z < 1$ galaxies	Sensitive R~10,000 imaging spectroscopy with large format arrays.
	What regulates SF in clouds within a galaxy? What is the role of magnetic fields?	[CII], [OI] and high-J CO in ~ 100 galactic clouds and the Galactic Center. Polarization maps over 10 sq. deg. OH^+ and H_2O in >100 dust sources	R ~ 300000, polarimetry from 30-300 μm, sensitivity to ~1% fractional polarization at 250 μm.

Science Theme	Questions	FIR Surveyor Observations	FIR Surveyor Capabilities
The buildup of heavy elements and the formation of habitable planets	What is the cosmic history of the growth of metals and dust?	Fine structure lines, PAH, silicate features and H_2 in galaxies to z~10. Spatially-resolved continuum observations of young SNRs	Sensitive wideband R~500 survey spectroscopy throughout the far-IR.
	What is the water trail from molecular clouds to habitable planets? What is the gas and volatile structure of protoplanetary disks?	High resolution spectra of water, CO, HD, and other gas-phase species in dense cores and protoplanetary disks; low resolution spectra of water ice features	R~300,000 spectroscopy for gas-phase lines, and moderate-R capability (R>100) at <60 μm for solid-state features.
	How do planetesimal systems evolve?	Atomic gas lines, water ice/vapor, and silicate features in debris disks; shape and peak position of 69 μm silicate feature	25-400 micron survey spectroscopy at R~500, and sensitive R~10,000 measurements of key gas-phase coolants.
	How was the architecture of the Solar System rearranged during its late-stage evolution.	Large area continuum sky survey with low spectral resolution to find & characterize TNO SEDs.	Sensitivity and mapping speed to cover thousands of square degrees to the continuum confusion limit.

FIR Survey Science Highlights

- A 2,500 hr pointed survey could detect the bright mid and far-infrared fine-structure lines in over 2000 galaxies, accurately measuring star-formation and AGN accretion rates in even the most dust enshrouded systems at $z > 2$-5.

- A 2000 hr, 3-D spectral survey over 10 sq. degrees would detect over a million galaxies in FIR line emission, including over 10^5 at $z > 3$, providing redshifts and physical conditions in a sample unbiased by UV/optical selection effects.

- A deep 2,000 hr survey of 1 square degree can uncover redshifted H_2 cooling lines from young, low-metallicity galaxies at $z \sim 5$-10, to a line luminosity of 10^9 - 10^{10} $L_\odot$

- A 2,000 hr survey could detect [CII] emission from extraplanar gas and relic outflows in 3,000 galaxies down to a HI column density of $N_H \sim 2\times10^{20}$ cm^{-2} for neutral gas with a density as low as 10 cm^{-3}, or detect the bright FIR cooling lines in thousands of Milky Way class galaxies out to $z \sim 1$.

- An all-sky continuum survey would find every TNO in the Solar System with a radius of 145 km out to 100 AU from the Sun, almost every 45 km radius object within 60 AU (the outer edge of the Kuiper Belt), and gather the largest census of objects down to 10 km in radius.

- A 2,000 hr spectroscopic survey of the Milky Way could find water down to 1% of Solar System abundance, allowing the measurement water vapor, water ice, and the determination of the location of the snow line in 1,000 proto-planetary disks around stars with masses as low as 20% of the mass of the Sun.

- A survey of the Magellanic Clouds could detect every dusty circumstellar disk in those galaxies down to a dust mass of 100 M_{Earth}.

Ways forward for the study

- The science of the FIR Surveyor is broad and exciting.
- It will have profound consequences for our understanding of the Universe on all scales – first stars and galaxies to habitable planets

- To move forward for the decadal survey, and maximize the science of the FIR Surveyor, we need work out the proper combination/balance of:

    - wavelength coverage, spectral resolution, collecting area
    - polarization capabilities
    - field of view and mapping speed
    - spatial resolution
    - Large surveys and GO science

And of course, determine the Cost as a function of all of the key design parameters.